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## METHOD AND APPARATUS FOR USING AN ON-BOARD TEMPERATURE SENSOR ON AN INTEGRATED CIRCUIT

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### BACKGROUND OF THE INVENTION

#### Field of the Invention

This invention relates to integrated circuits and systems and more particularly to use of a temperature sensor on an integrated circuit.

#### Description of the Related Art

Computer systems have typically relied on external temperature sensors located in the proximity of the processor package to provide temperature information for thermal control. The external temperature sensor provides the temperature information to logic external to the processor, which utilizes the sensed temperature to provide appropriate thermal control functions, e.g., turning a fan on and off.

It would be desirable to incorporate temperature sensing directly onto the integrated circuit whose temperature is being measured to provide a more accurate temperature measurement of the integrated circuit die. Further, it would be desirable to provide appropriate logic on the same integrated circuit whose temperature is being measured to evaluate that temperature measurement and provide appropriate signals capable of being utilized to provide thermal control functions directly or indirectly.

### SUMMARY OF THE INVENTION

Accordingly, in one embodiment, the invention provides an integrated circuit that includes a temperature sensor providing a temperature of the integrated circuit. A storage location on the integrated circuit stores a first temperature limit value. Compare logic is coupled to provide an indication of a comparison between the

temperature and the first temperature limit value. In one embodiment, the integrated circuit asserts a temperature control signal on a first output terminal when the temperature indicated by the temperature sensor is above the first temperature limit value.

5 In an embodiment, there are two modes of operation which can be specified to deassert the temperature control signal. In one mode, the integrated circuit deasserts the temperature control signal supplied on the first output terminal when the temperature indicated by the temperature sensor falls below a programmable second temperature limit value. In another mode, integrated circuit deasserts the temperature control signal supplied on the first output when a control location in the integrated circuit is accessed. The integrated circuit may further include an addressable storage location coupled to the temperature sensor, which supplies an indication of the temperature on the integrated circuit.

15 The integrated circuit may further include a second output terminal coupled to provide external to the integrated circuit an asserted signal when the temperature indicated by the temperature sensor is above a second temperature limit value.

20 In another embodiment, the invention provides a method that includes, measuring a temperature of an integrated circuit with a temperature sensor, the temperature sensor being part of the integrated circuit; comparing the measured temperature to a first temperature limit value stored in the integrated circuit; and generating a signal on a first output terminal of the integrated circuit according to the comparison. In one embodiment, the signal is asserted when the measured temperature is greater than the first temperature limit value. In one embodiment, the first signal on the output terminal is deasserted when a control location on the integrated circuit is accessed or when the measured temperature goes below a lower limit value, according to a programmable mode of operation.

The method may further include comparing the measured temperature to a second temperature limit value stored in the integrated circuit; and asserting a second signal on a second output terminal of the integrated circuit when the measured

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**FIG. 1** illustrates a high level block diagram of an exemplary system incorporating an embodiment of the present invention.

**FIG. 3** illustrates an exemplary control byte showing the control functions used in an embodiment of the invention.

### **DESCRIPTION OF THE PREFERRED EMBODIMENT(S)**

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The temperature measurement, regardless of the type of temperature sensor, is compared to temperature limit values from registers 105 in compare logic 107. The compare logic determines if the measured temperature is above or below thresholds established in limit registers 105. Based on that comparison, processor output terminals 112 and 114 are driven to indicate the needed system action to be taken such as activating or deactivating a cooling device 109.

One of the limit values may be a panic limit value indicating a threshold temperature for safe processor operation. If the panic limit value is exceeded by the measured temperature, TPANIC output terminal 112 is asserted. Another of the output terminals, TALERT output terminal 114, may be used in several modes as explained further herein to provide thermal control information.

In an embodiment, various limit values and control functions can be programmably controlled in the microprocessor. Referring to Fig. 2, an exemplary address block 200 is illustrated that provides registers used for the various functions associated with the thermal control functions described herein. Note that while address block 200 may be implemented as a plurality of contiguous bytes, each of the described fields may be independently addressable. In one implementation each of the illustrated fields is byte length.

Referring to Figs. 1 and 2, temperature sensor 103 provides the current temperature measurement which, in one implementation, is expressed as an unsigned 7-bit value to temperature field 202 in address block 200. That register may be read by the processor to determine the current temperature indicated by temperature sensor 103.

Register 203 stores a programmable panic limit, which indicates a safe limit of operation. In one embodiment, the panic limit is implemented as a seven bit unsigned number and is preferably implemented as a read/write field. Operating the processor above the panic limit risks thermal damage to the processor. Thus, output terminal TPANIC 112 is asserted when compare logic 107 indicates the current temperature has exceeded the safe limit of safe operation. Assertion of TPANIC output terminal 112 should activate hardware and/or software to take immediate and possibly drastic actions to avoid thermal damage to the processor. For example, TPANIC may be

used to drive an interrupt or may be connected directly to a cooling device. TPANIC may also be used to shut down the power supply to avoid potential damage, if necessary. Once asserted, TPANIC can be cleared by writing (or otherwise accessing) a control bit in the processor.

5           Registers 205 and 207 store, respectively a lower limit temperature value and an upper limit temperature value. In one embodiment, each limit value is implemented as a seven bit unsigned number. The measured temperature value from temperature sensor 103 is compared to the upper and lower limit values that are written to registers 205 and 207. The comparison result is used to drive the output terminal TALER 114. As previously mentioned, TALER output terminal 114 can operate in several modes, a "thermostat" mode and an "interrupt" mode.

15           In thermostat mode, TALER is asserted when the die temperature as measured by temperature sensor 103, rises above the upper limit value in register 207 and is deasserted when die temperature falls below the lower limit value defined in lower limit register 205. In thermostat mode, TALER can be used to control a cooling fan or other cooling device, much like the thermostat in a building turns the air conditioning on and off to maintain the room temperature within an appropriate range.

20           In interrupt mode, TALER is asserted when the die temperature rises above the upper limit value specified in upper limit register 207 and is de-asserted when software writes a control bit described further herein. In interrupt mode, TALER may be used as a hardware interrupt signal. In response to assertion of TALER, an interrupt service routine activates a cooling device as needed. The same service routine would be responsible for accessing a location, e.g., writing a register bit, that deasserts TALER and its hardware interrupt.

25           A status field is supplied in 201 that supplies the status of both TALER and TPANIC (one bit each), i.e., whether the respective output terminal is asserted.

1           Note that the panic limit and lower and upper limit registers are shown generically as temperature limit registers 105 in Fig. 1.

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Three control bits in the illustrated embodiment are used to control operation of TPANIC output terminal 112. The set TPANIC when temperature is greater than the panic limit (SPGL) bit 308 enables operation of the TPANIC output terminal. As previously mentioned, once TPANIC output terminal 112 is asserted, accessing (e.g., writing) a control location such as the Reset Panic (RP) 306 bit can be used to reset the TPANIC output terminal 112. The TPANIC polarity bit 307 determines the polarity of an asserted TPANIC signal.

In an embodiment of the invention, all of the features can be disabled by resetting or not setting the appropriate control bit. Thus, in such an embodiment, if not intentionally enabled, the TALERT and TPANIC capability remains inactive. Thus, a processor according to an embodiment of the invention, can function in old system boards without design modifications.

The registers, bytes and/or bits used to monitor and control the thermal capabilities described herein may be mapped into processor input/output space at an offset from an I/O location set in a model specific register (MSR). In that way, it should be possible for the basic input/output system (BIOS) to map the thermal register(s) in a manner that does not interfere with other I/O devices or require new hardware to be added to system designs. Likewise, the BIOS should be able to re-map other I/O devices so they do not interfere with the chosen addresses for the thermal registers. Thus, in one embodiment, the ability is given to access the thermal registers through mapped I/O space in a way that does not interfere with other system I/O devices or require new hardware to be added to system designs. Alternatively, the registers containing the thermal control and status information shown in Figs. 2 and 3 may reside in one or more model specific registers, whose access may be restricted to software having the appropriate privilege level.

Referring to Fig. 4, an exemplary mobile system incorporating an embodiment of the present invention is illustrated. Processor 401 supplies TALERT output signal 402, which is coupled to directly control the speed of fan 405 through AND gate 407. A PIIX4 compatible input/output integrated circuit 409, known in the art as a South Bridge, receives the TPANIC alert 403 and performs an appropriate thermal failsafe action, e.g., stopping processor operations, if necessary, to safeguard the system when

the TPANIC alert 403 is asserted. AND gate 407 also receives a general purpose output (GPOn) control from South Bridge 409, which can be used to enable direct control by processor 401 of fan 405. South Bridge 409 performs other power management functions in the system, known in the art, which are not necessary for understanding of the present invention and thus are not described herein. In operation, BIOS post code can set the I/O address(es) for the thermal logic and setup the appropriate thermal management mode. In one embodiment, Advanced Configuration and Power Interface (ACPI) software, which enables the operating system to control the power management functions within the system, can be used to monitor die temperature. In a passive cooling mode, ACPI can throttle processor operations, i.e., reduce effective clock frequency using the STPCLK# input in response to die temperature. In active cooling modes fan 405 can be controlled directly by TALERT 402 as illustrated.

Thus, an on-board temperature sensor system has been described that provides more accurate and simpler thermal control functions. The ability to locate the sensor and the thermal registers (including the limit and control registers) on the processor and making the thermal control registers readily accessible to software operating on the processor, such as software implementing ACPI, simplifies thermal management of the computer system and provides more flexible thermal management capabilities.

The description of the invention set forth herein is illustrative, and is not intended to limit the scope of the invention as set forth in the following claims. For instance, the temperature logic, while described with relation to a processor, may be implemented on other integrated circuits. Further, the control registers may be implemented in a variety of manners as would be known to one of skill in the art. Some or all of the temperature control functions described herein may be implemented in a particular design based on system requirements. Note also that numerous variations of on-chip thermal sensors are known in the art. All such variations are included within the spirit and scope of the present invention. Other variations and modifications of the embodiments disclosed herein, may be made based on the description set forth herein, without departing from the scope and spirit of the invention as set forth in the following claims.